NASA-DoD Combined Environments Testing Results

Presented
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Raytheon
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Overview

- Combined Environments Testing
  - Early Life Failures
  - Low & High Number of Defects
  - 2P Weibull Plot Not Good Fit
  - CSP-100 CTF Higher Than Expected
  - ENIG Sample Size Too Small
- Results
- Statistical Analysis
- Conclusions
- Questions

Combined Environments Testing

- Combines Thermal Cycling and Vibration Testing
- Based on Modified Highly Accelerated Life Test (HALT)
- Benefits
  - Identify Design and Process Problems
  - Time Frame is Shorter and Faster
  - Sample Size can be Smaller

Combined Environments Testing

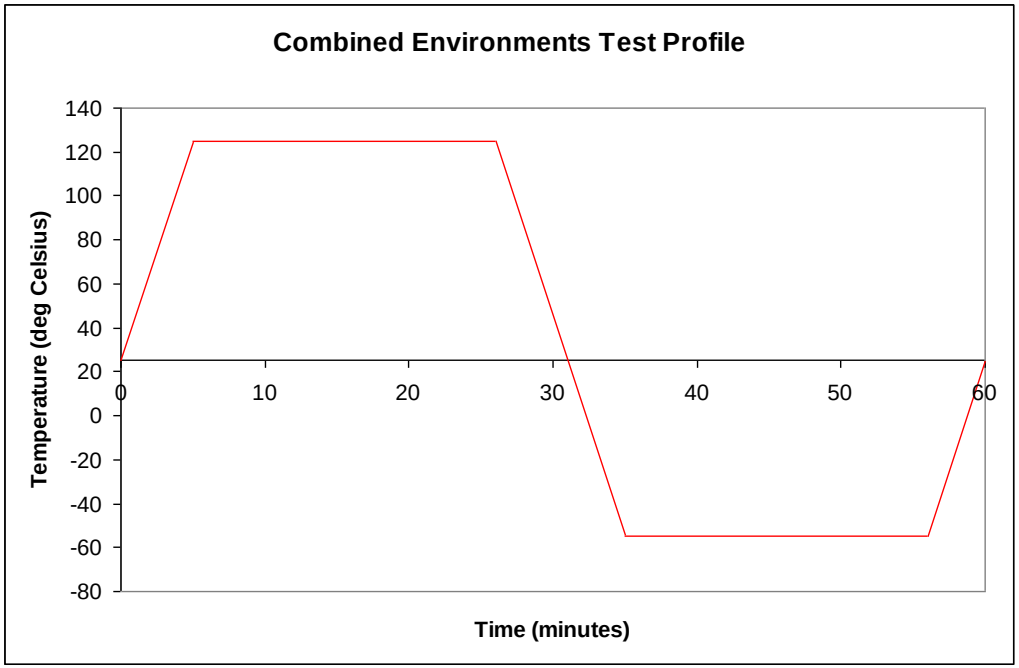
- Possible Problems
  - Stressed Beyond Typical Use Environments
    - Thermal Extremes
    - Thermal Rate of Change
    - Vibration
  - Not a True Life Test
- Compare Lead-Free Solder Performance Against Baseline Tin-Lead Eutectic Solder

Combined Environments Chamber

- Thermal
  - Thermal Capability Ranges from -100 to 200°C
  - Ramp Rates of Up to 60°C per Minute
- Vibration
  - Maximum Levels of ≥ 60 g_{rms}
- Thermal and Vibrations can be Applied Separately or Combined

Combined Environments Test Parameters

- Thermal
  - -55 to 125°C Temperature Cycles
  - 20°C per Minute Ramp
  - 15 Minute Soak
- Vibration
  - 10 g_{rms}, Initial
  - Increased by 5 g_{rms} Every 50 cycles
  - Maintained During Cycles
  - 55 g_{rms}, Maximum



Combined Environments Test Parameters

- Test Vehicles
  - 16 Manufactured
  - 11 Rework
- Monitored with Event Detector
- Vibration Monitored on Mfg Test Vehicles, Randomly Placed
- Randomized Test Set-up

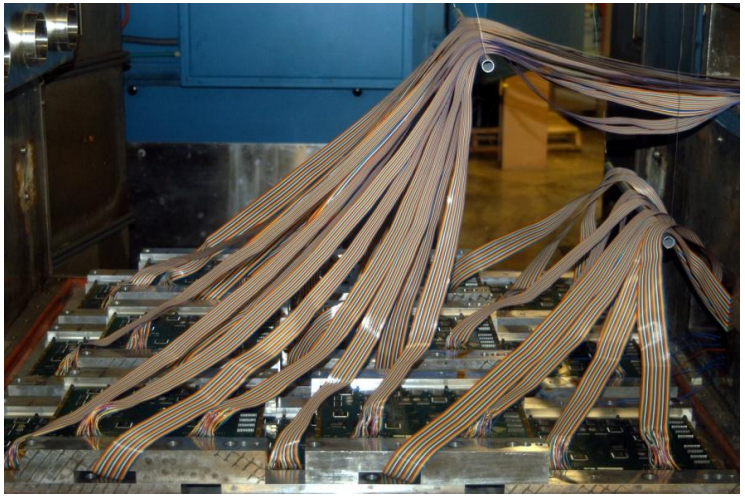
Monitored with accelerometer
Monitored with thermocouple

Manufactured Test Set-up		
Bottom Layer		
23	69	71
118	22	120
73	20	24

Top Layer	
116	72
21	70
119	117

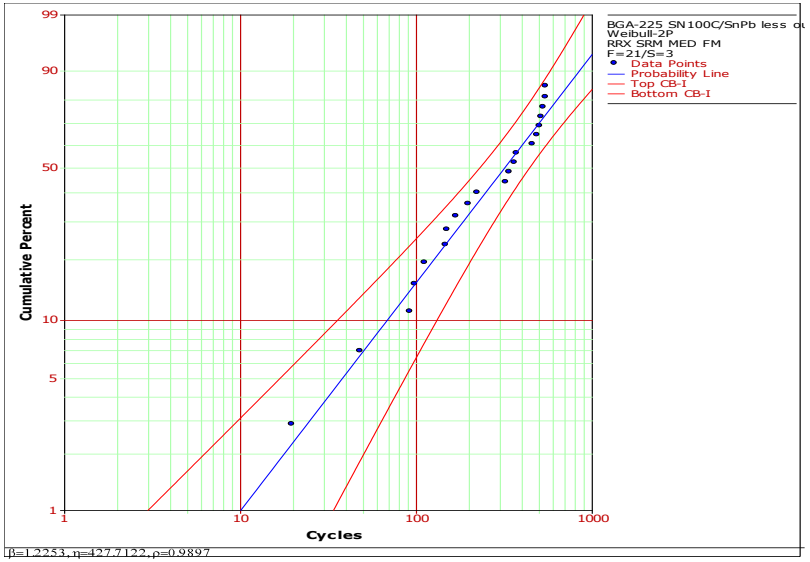
Rework Test Set-up		
Bottom Layer		
181	140	142
158	139	183
163	143	97

Top Layer	
180	N/A
182	N/A
141	N/A



Early Life Failures

- Failures Less Than 10 Cycles
  - Treated as Outliers
- Two Weibull plots
  - One Showing Outliers
  - Second Plot Without
- Example
  - Mfg SN100C/SnPb BGA-225



Early Life Failures

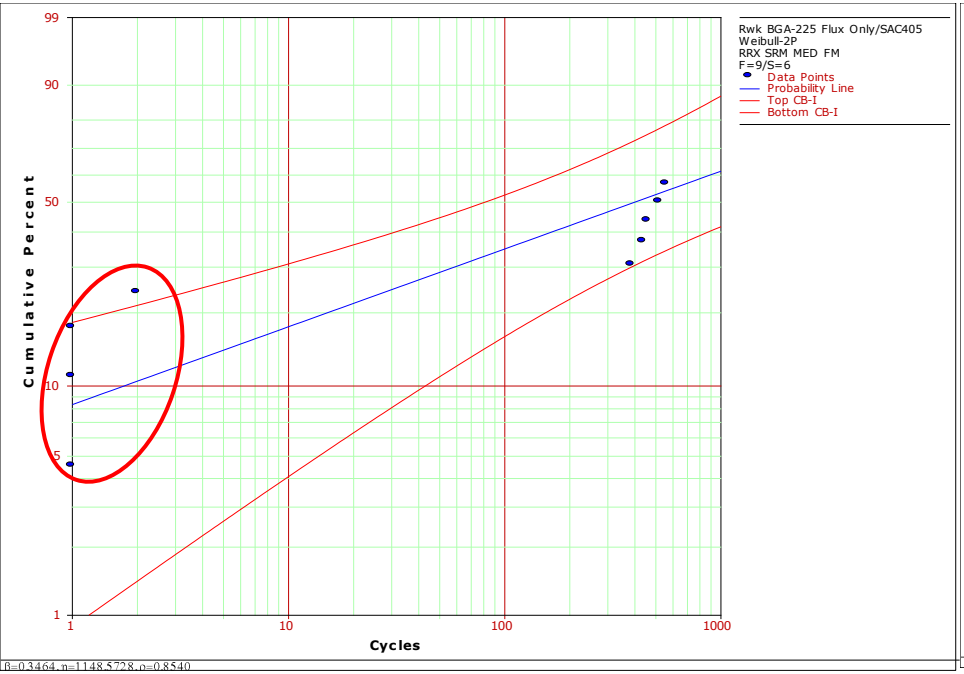
- Most Outliers Occurred on Reworked Test Vehicles
- Examples:
  - Rwk Flux Only/SAC405 BGA-225 (Rwk)
  - Rwk SnPb/Sn TSOP-50 (Rwk)
  - Rwk ENIG SnPb/SAC405 BGA-225 (Rwk)
  - Rwk SnPb/SAC405 BGA-225 Batch B (Rwk)
  - Rwk SAC305/SAC305 TQFP-144

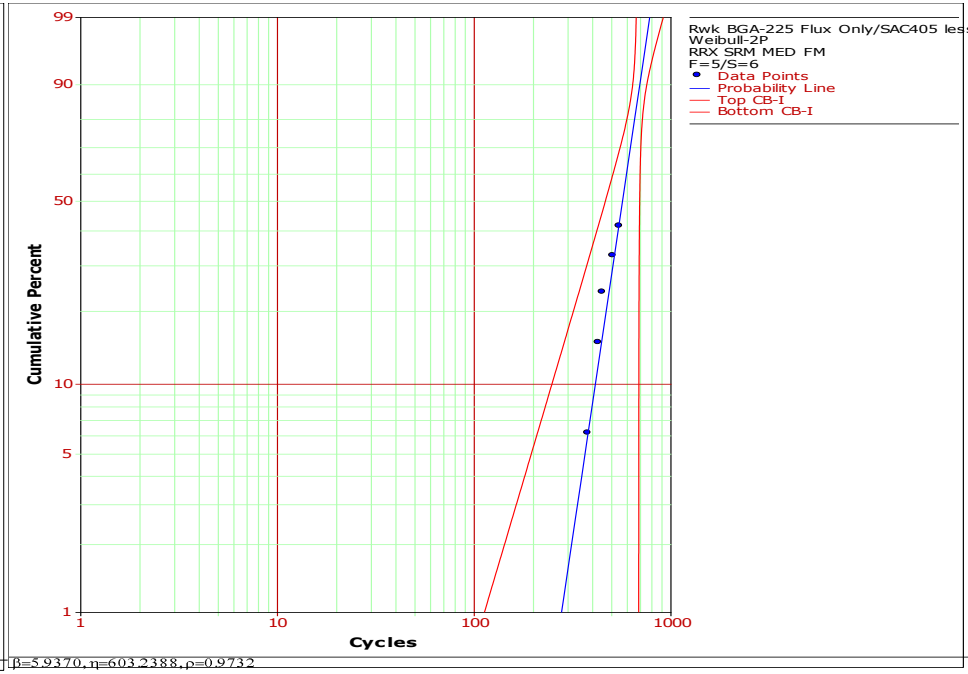
Rework Early Life Failures

- Rework Processing Difficult
  - Unplanned Rework
  - Some Components Reworked More Than Once
- BGA Rework Processing Difficult

Batch A - Lead-Free Rework								
Test Vehicle	**Component Location**	**Component Type**	**Original Component Finish**	**Reflow Solder Alloy**	**New Component Finish**	**Rework Solder**	**Scheduled for Rework**	**Total # of Reworks**
SN180	U04	BGA-225	SnPb	SAC305			No	1
SN180	U05	BGA-225	SnPb	SAC305			No	1
SN180	U43	BGA-225	SAC405	SAC305	SAC405	SnPb	Yes	2
SN181	U18	BGA-225	SAC405	SAC305	SAC405	SnPb	Yes	2
SN181	U56	BGA-225	SAC405	SAC305	SAC405	Flux Only	Yes	2

Rwk Flux Only/SAC405 BGA-225





Key = Solder alloy/Component finish

- Shown Using Same Scale
- 2P Weibull Fit Affected by Outliers

Low Number of Defects

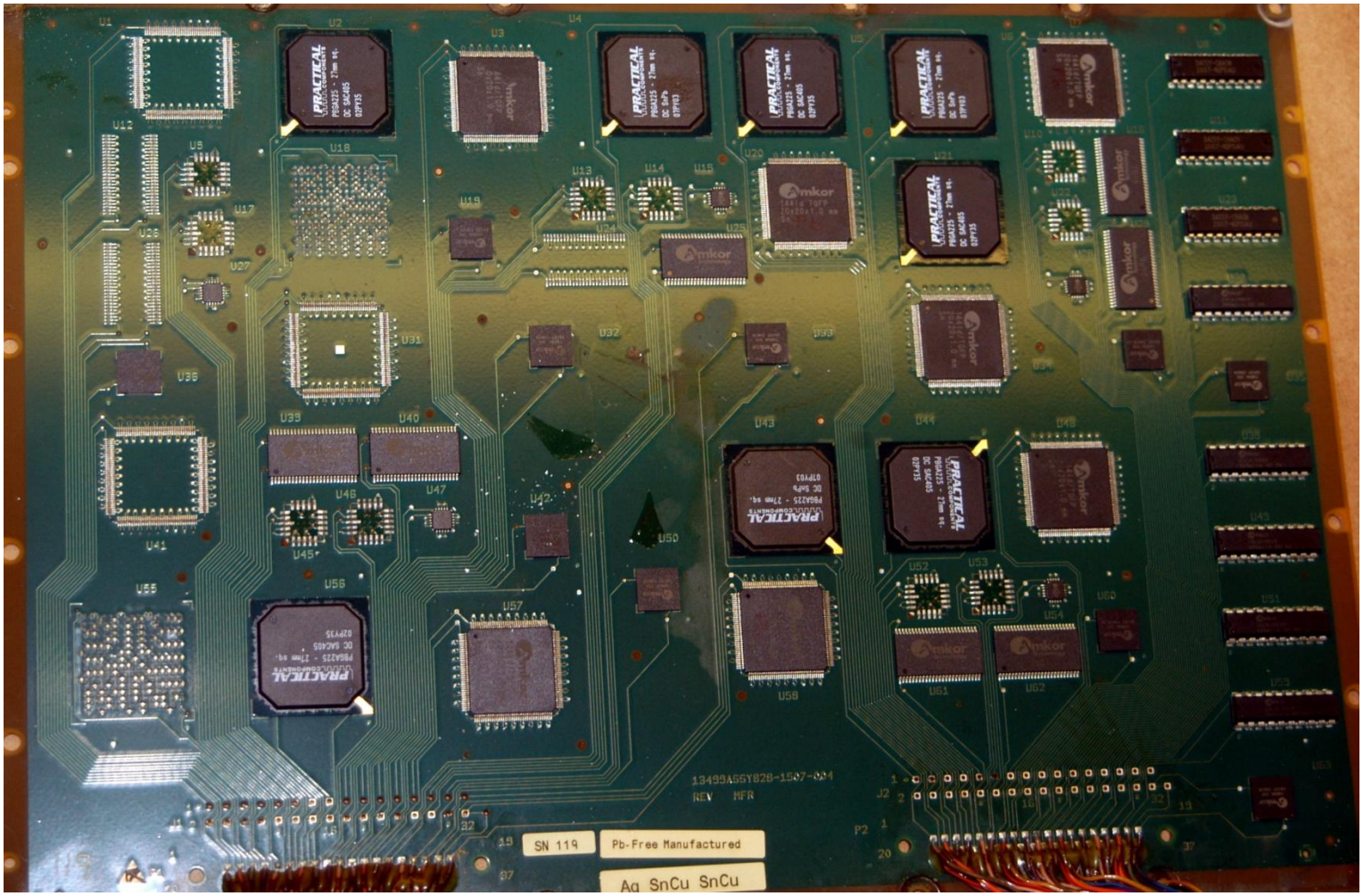
- Test Vehicles with 20 or Fewer Failures
  - Run 1 (Mfg) – TV SN 23, 69 and 116 and ENIG TV SN 97 (*Tested in Run 2*)
  - Run 2 (Rwk) – TV SN 142 and 183
- Run 1 Failed A Higher Percentage of Components Than Run 2
- Possible Causes for Low Fails
  - Mechanical Issues with Chamber
  - Location of TVs in Chamber

Causes for Low Failures Between Run 1 and Run 2

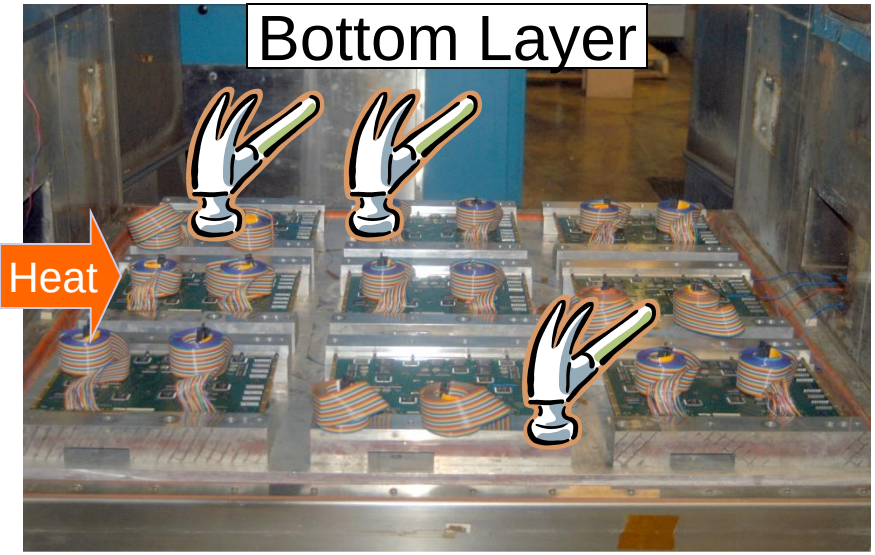
- Mechanical Issues with Chamber
  - Run 1 – Manufactured, ***Qty 15 TVs***
    - Chamber Shut Down for Maintenance and Repair
    - Learning Curve Controlling Vibe levels
  - Run 2 – Rework, ***Qty 12 TVs***
    - Weight Distribution Not the Same
    - Air Flow Not the Same
- Location of TVs in Chamber
  - Three Hammers Replaced Between Runs

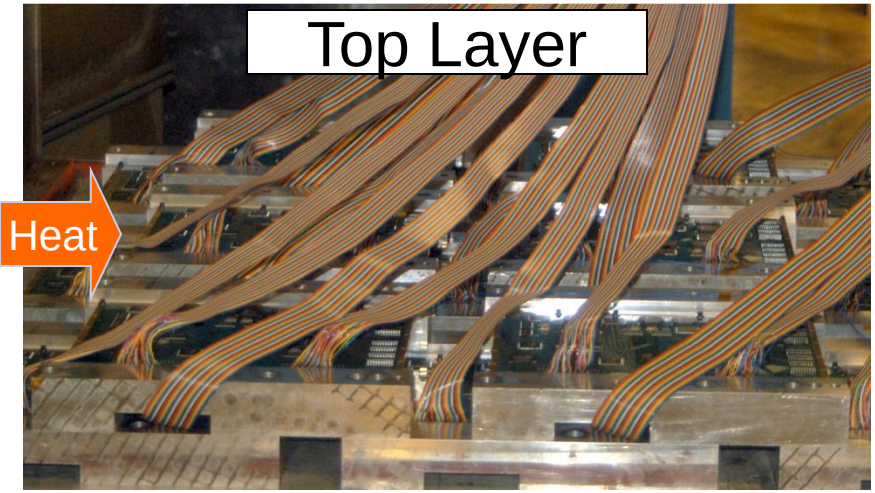
High Number of Failures

- TV SN 119 – Located Next to Heat Source



Location of TVs in Chamber





Run 1

Manufactured Test Set-up		
Bottom Layer		
✗	✗	71
118	22	120
73	20	24

Top Layer	
✗	72
21	70
119	117

Run 2

Rework Test Set-up		
Bottom Layer		
181	140	✗
158	139	✗
163	143	✗

Top Layer	
180	N/A
182	N/A
141	N/A

Monitored with accelerometer

Monitored with thermocouple

✗ - Low Fails

○ - High Fails

 - Hammer replaced

Discussion of Effect on TVs

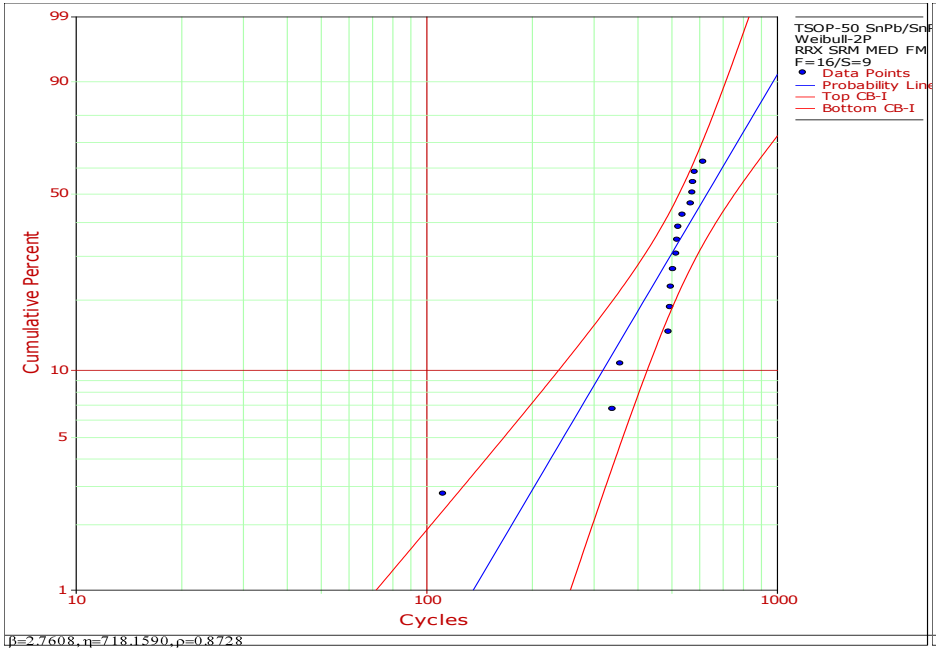
- Test Chamber
- Prior to Maintenance
  - Vibe Table Running Inefficient in Three Locations
  - Hammers Under TV SN 23, 69, 116 Running Inefficiently
    - Less Stress to Those Located Above Area

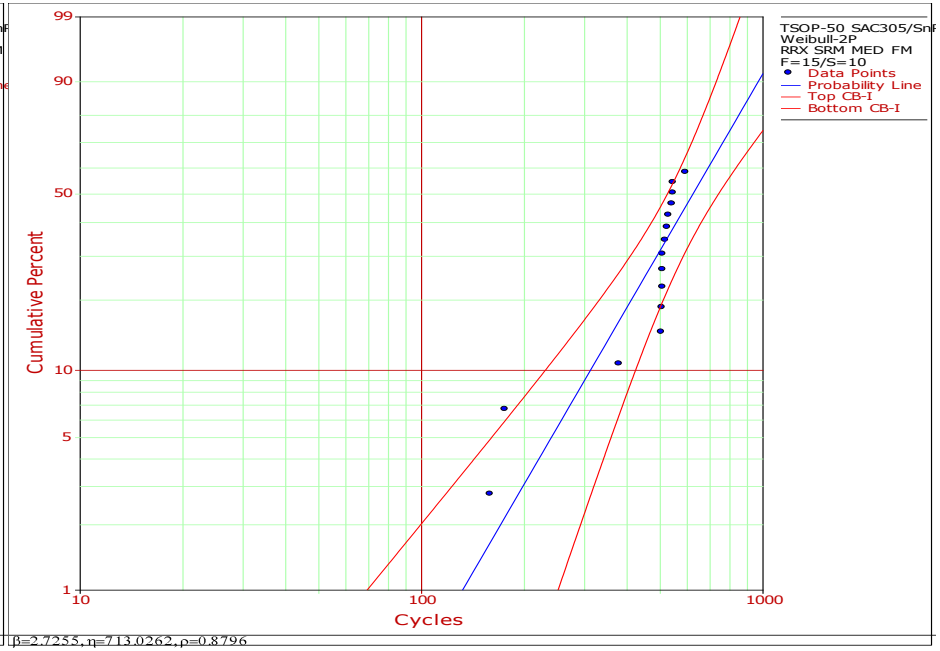
Discussion of Effect on TVs

- Maintenance Performed
  - Three Hammers Replaced Between Run 1 and Run 2
  - Fine Tuning Performed Prior to Run 2
- As a Result
  - Hammers Distribute Vibe Efficiently in Run 2
  - Less Stress to Boards
  - Fewer Component Failures to Rework TVs

2P Weibull Not Good Fit

- 2P Weibull Plots Not Best Fit for Some Data
  - Examples of $\rho < 0.95$:





- Mfg TSOP-50 SnPb/SnPb
  $\rho = 0.8728$
  Stair Step ~500 - 550 cycles

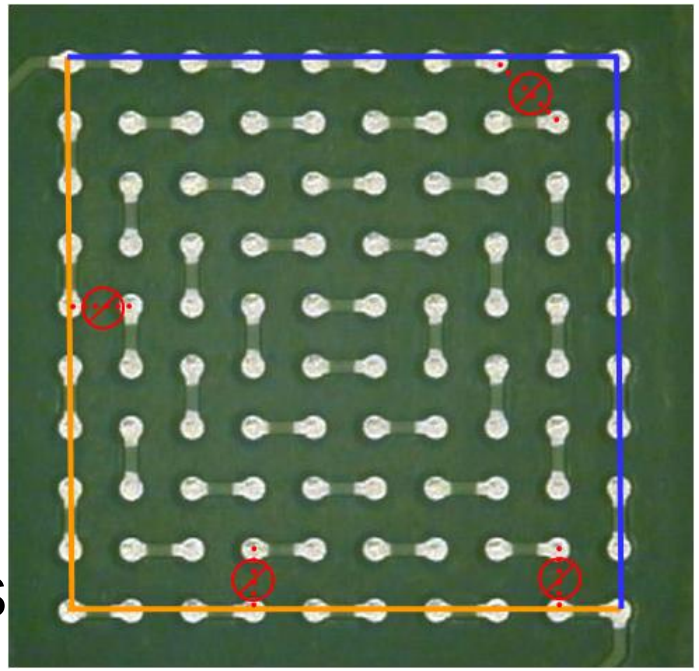
- Mfg TSOP-50 SAC305/SnPb
  $\rho = 0.8796$
  Stair Step ~500 - 550 cycles

What Happened after 500 Cycles?

- Manufactured TVs at 500 Cycles
  - Vibration Levels were 55 g_{rms}
  - Vibe Table Strained to Maintain Specified level
- Attribute Stair Step to Noise
  - Mechanical Issues
  - Chamber Maximum Vibe is ~60 g_{rms}
  - Properties of Solder Changed
  - Indication of a New Failure Mode
- ★ Previous CET HALT and Thermal Cycle Testing Had Similar Phenomena

CSP-100 CTF Higher Than Expected

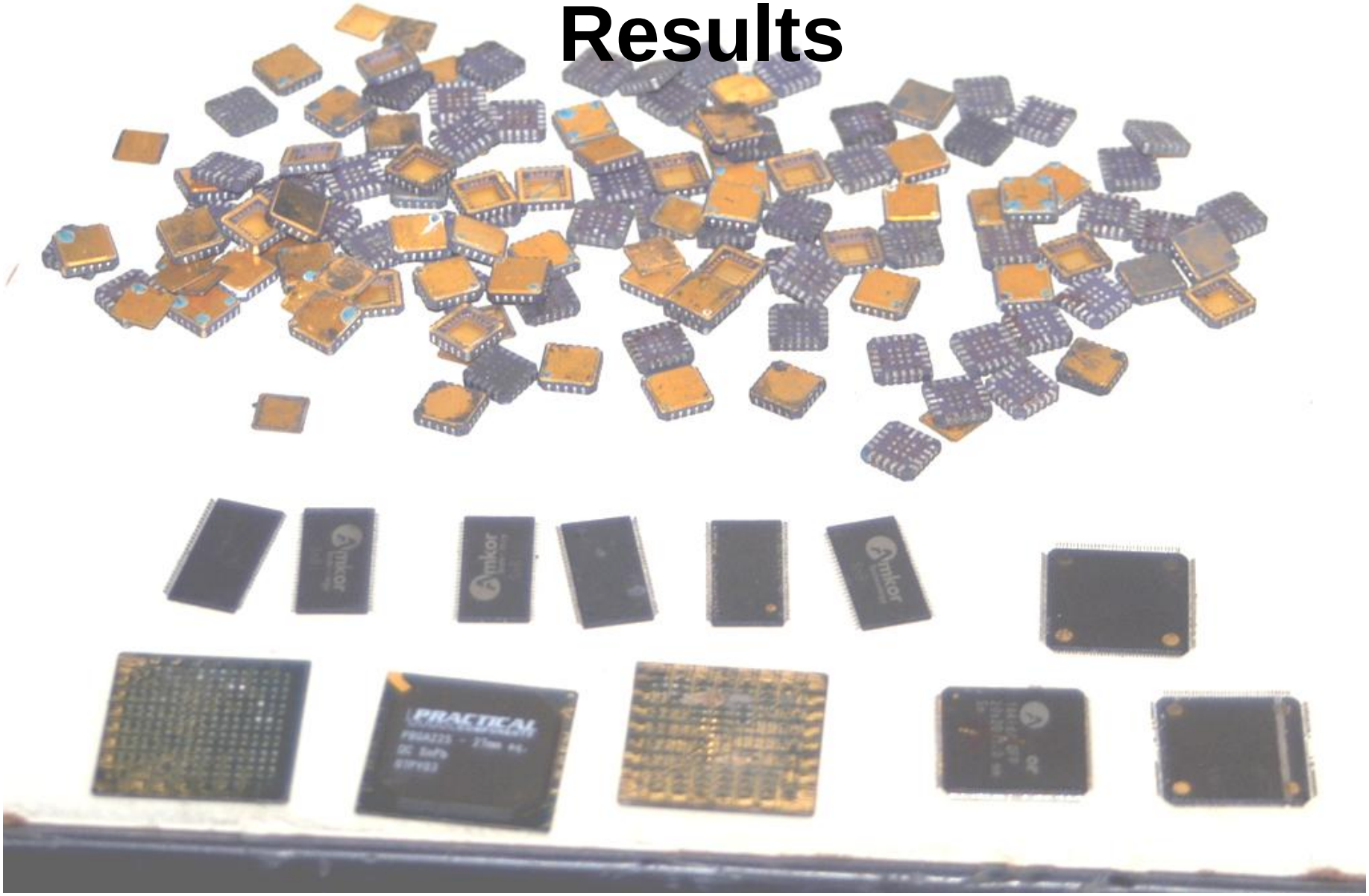
- Affected by
  - Incorrect Component Configuration in Drafting
  - Both Sides of Continuity Loop *Must* Break to Record an “Event”
- 2P Weibull Plots are *not comparable* to other Components
- Data Analysis Factor Must be Calculated for Reliability Comparison



ENIG Sample Size Too Small

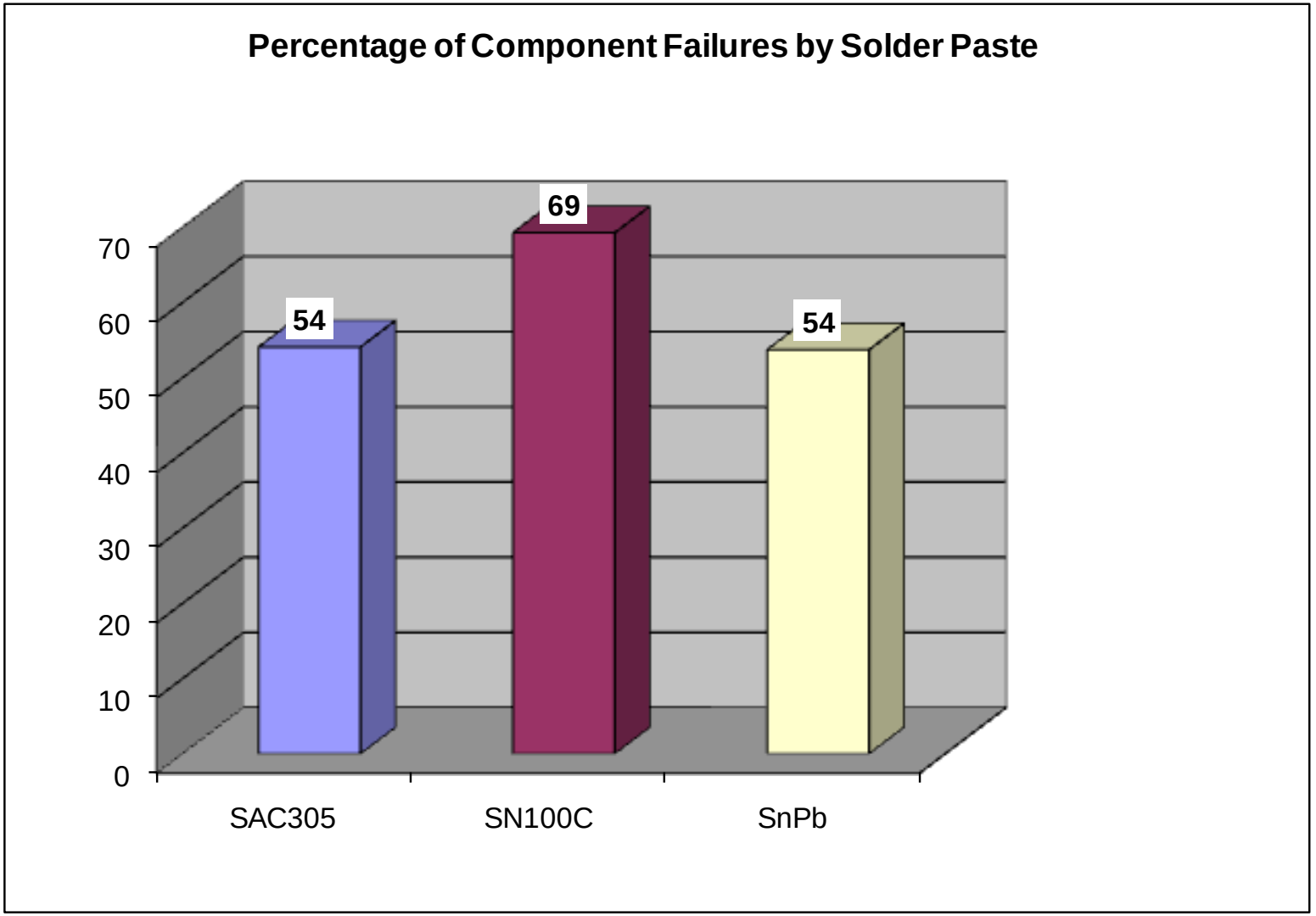
- Two ENIG TVs Tested in Run 2 (Rwk)
  - **Mfg TV SN 97**
    - 14 Total Components Failed
      - 5 of 14 were BGA-225 SnPb/SAC305
  - **Rwk TV SN 158**
    - 31 Total Components Failed
      - 10 of 31 were CLCC-20 SAC305/SnPb (Not Reworked)
- ENIG Data Not Included in Variance Component Analysis

Manufactured Test Vehicle Results



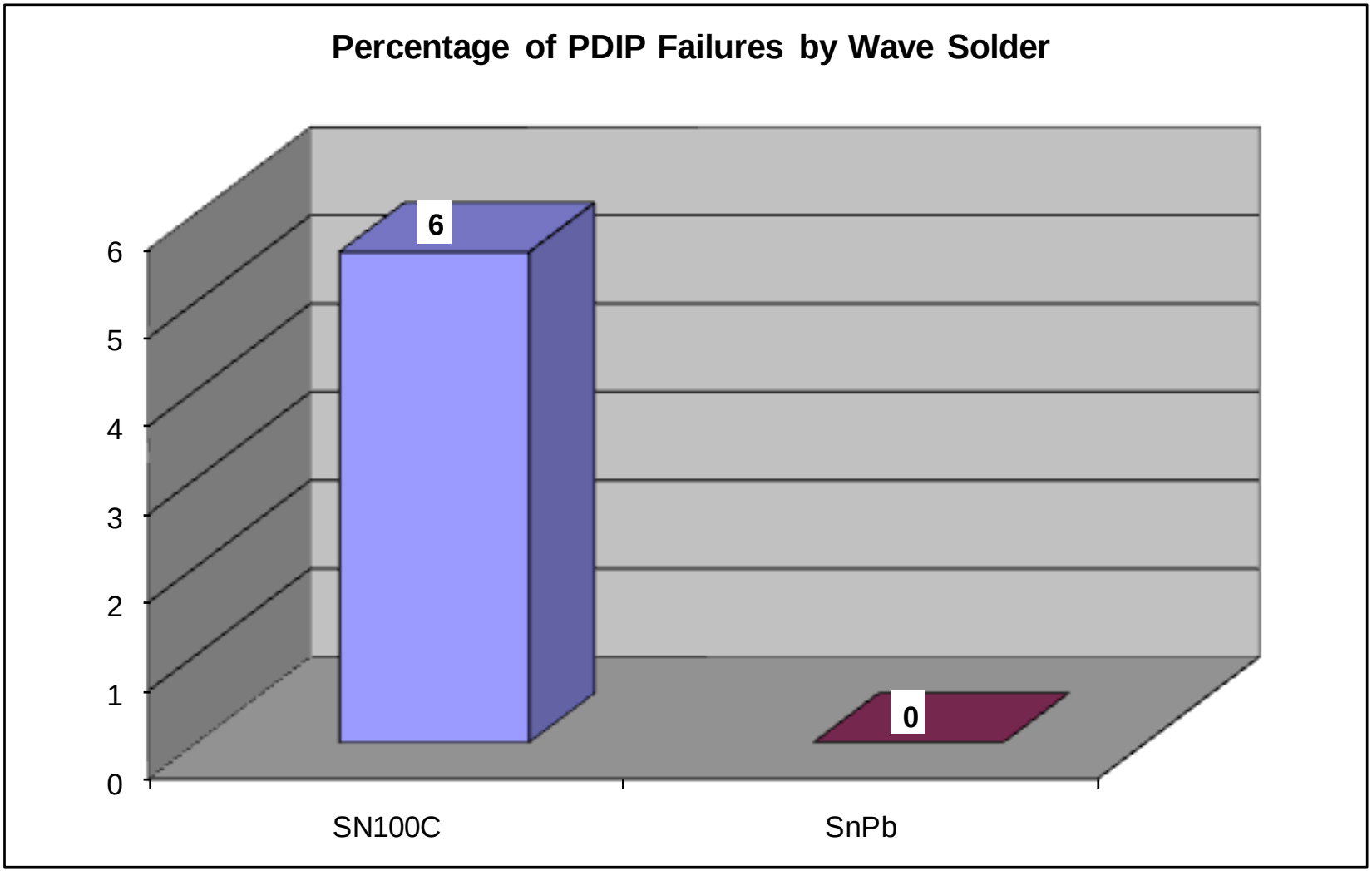
Summary of Manufactured Results

- SAC305 Failures equivalent to SnPb



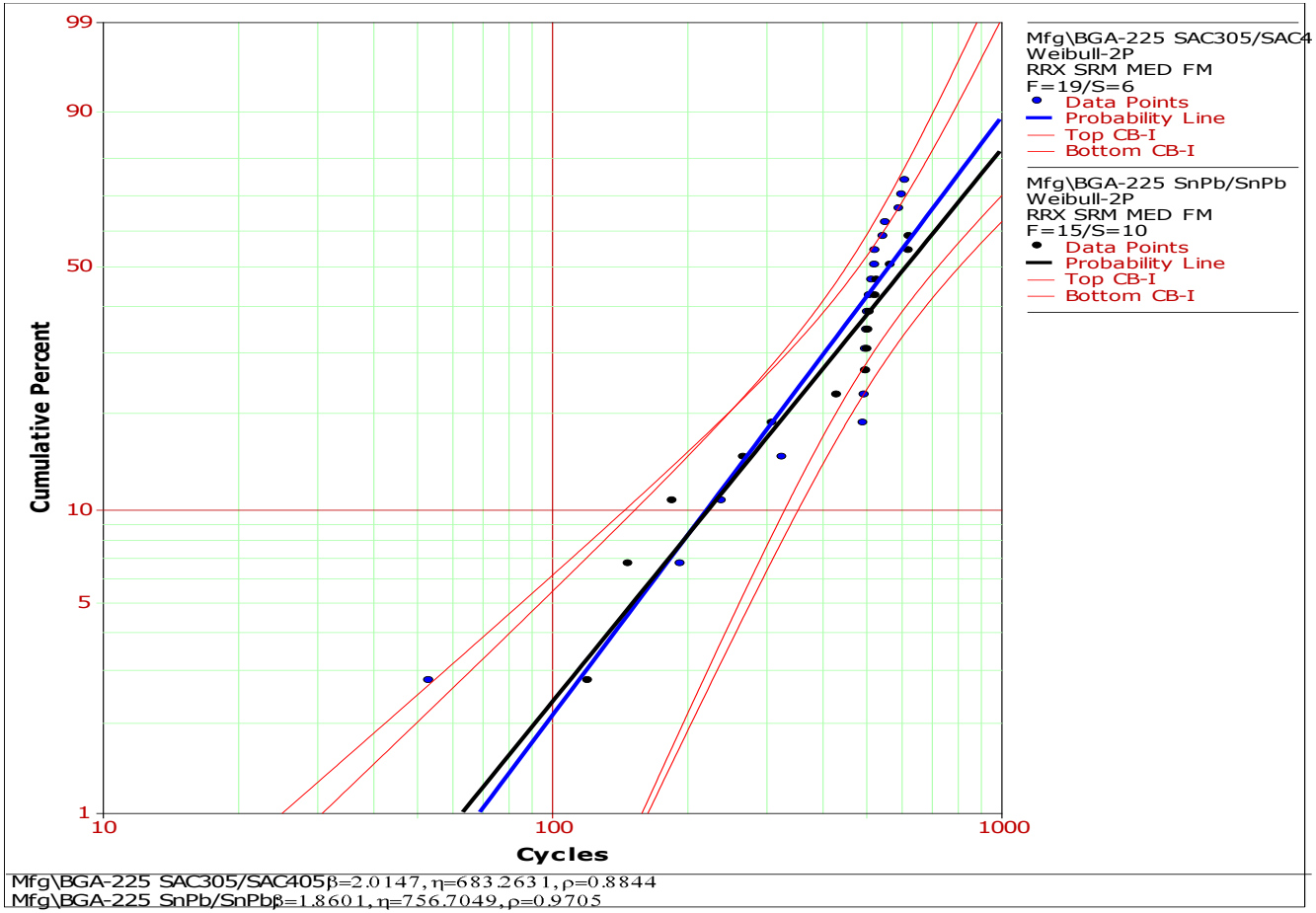
Overall Manufactured PDIP Results

- SnPb had Zero Failures



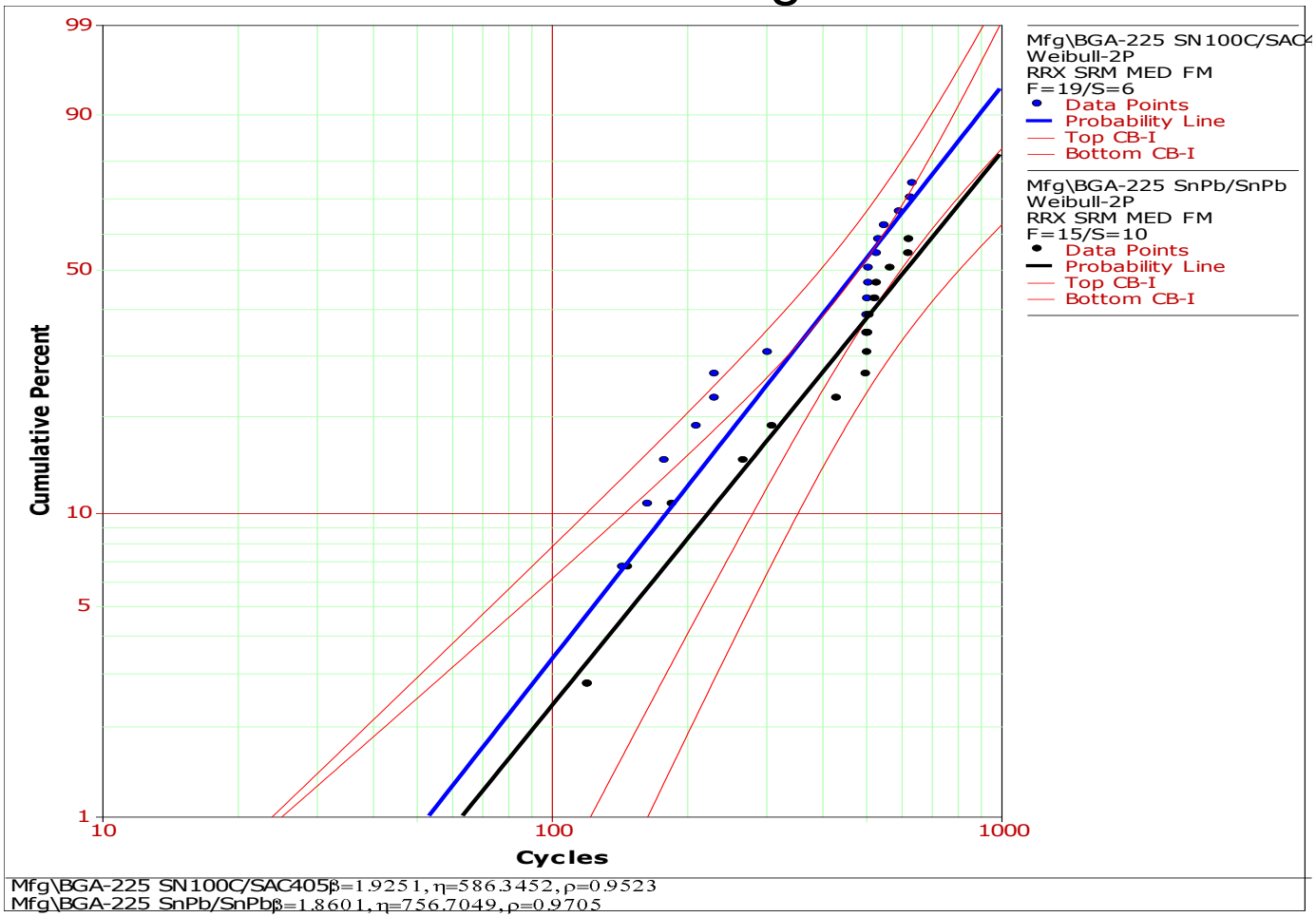
Mfg Lead-Free Solder Comparison

- BGA-225 SAC405/SAC305 vs SnPb/SnPb
  - Probability of Tin-Lead Lasting Longer Than SAC405/SAC305 is 54% - Not Statistically Significant



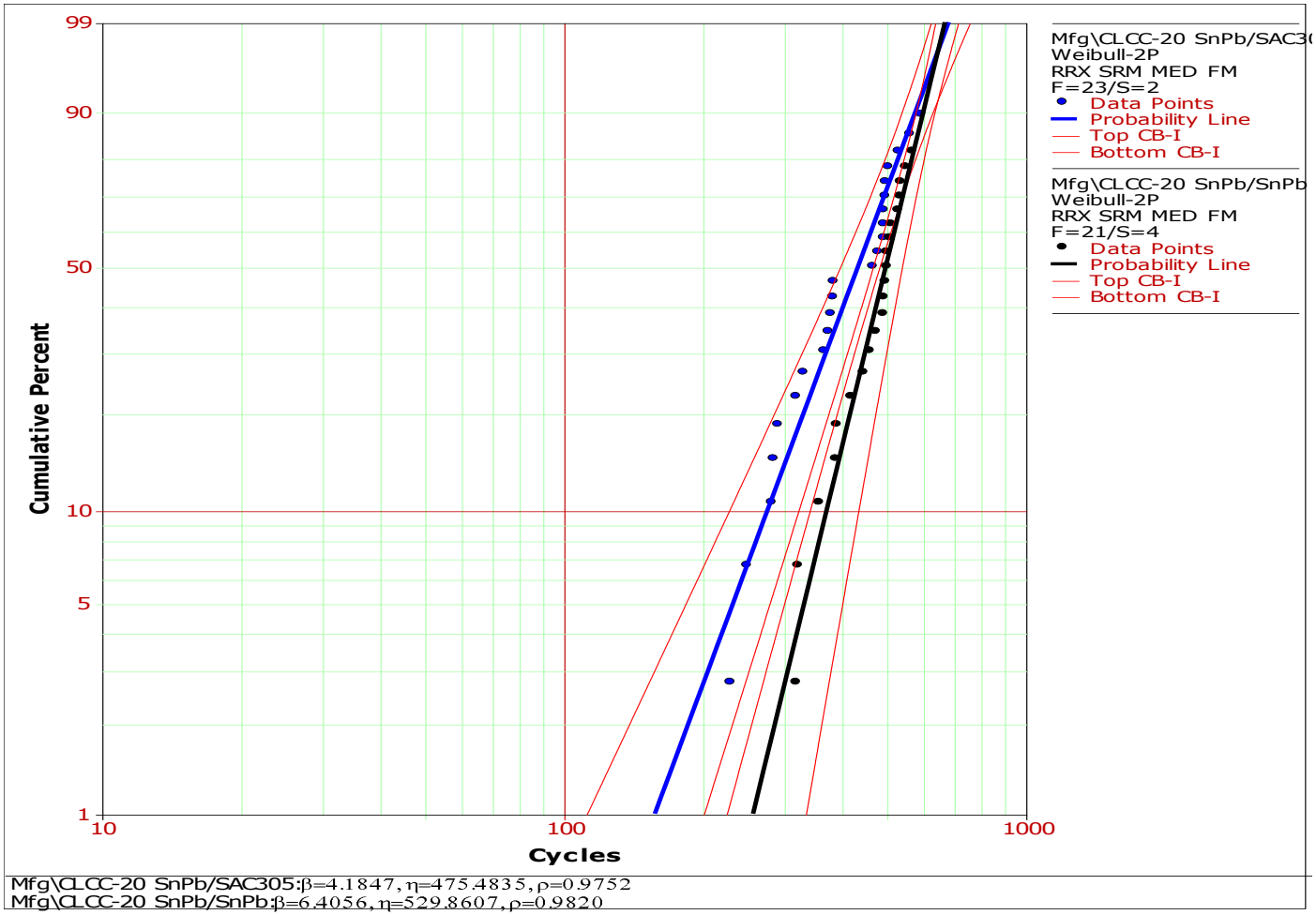
Mfg Lead-Free Solder Comparison

- BGA-225 SN100C/SAC405 vs SnPb/SnPb
  - Probability of Tin-Lead Lasting Longer Than SN100C/SAC405 is 62% - Significant



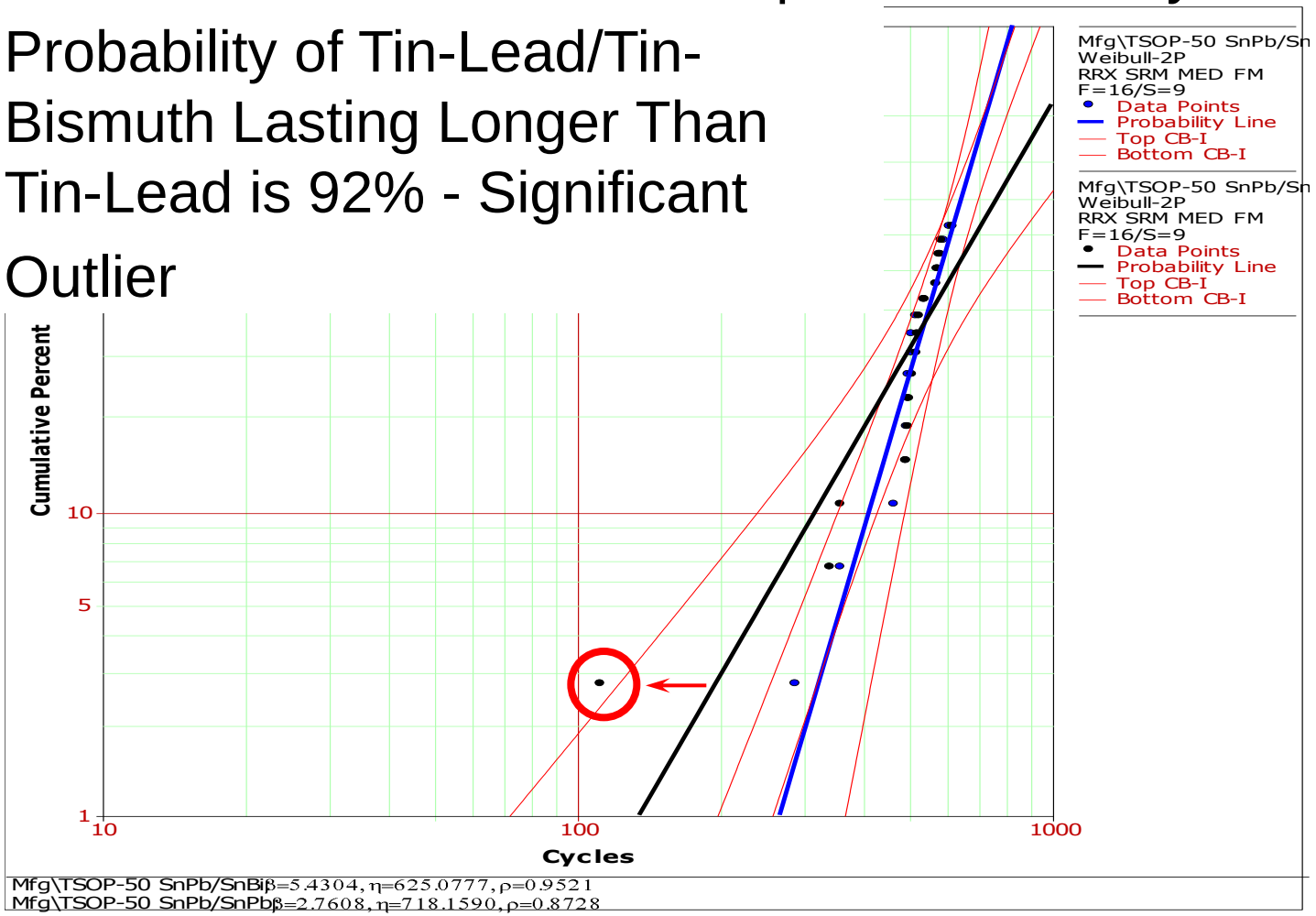
Mfg Lead-Free Solder Comparison

- CLCC-20 SnPb/SAC305 vs. SnPb/SnPb
  - Probability of Tin-Lead Lasting Longer Than SnPb/SAC305 is 66%

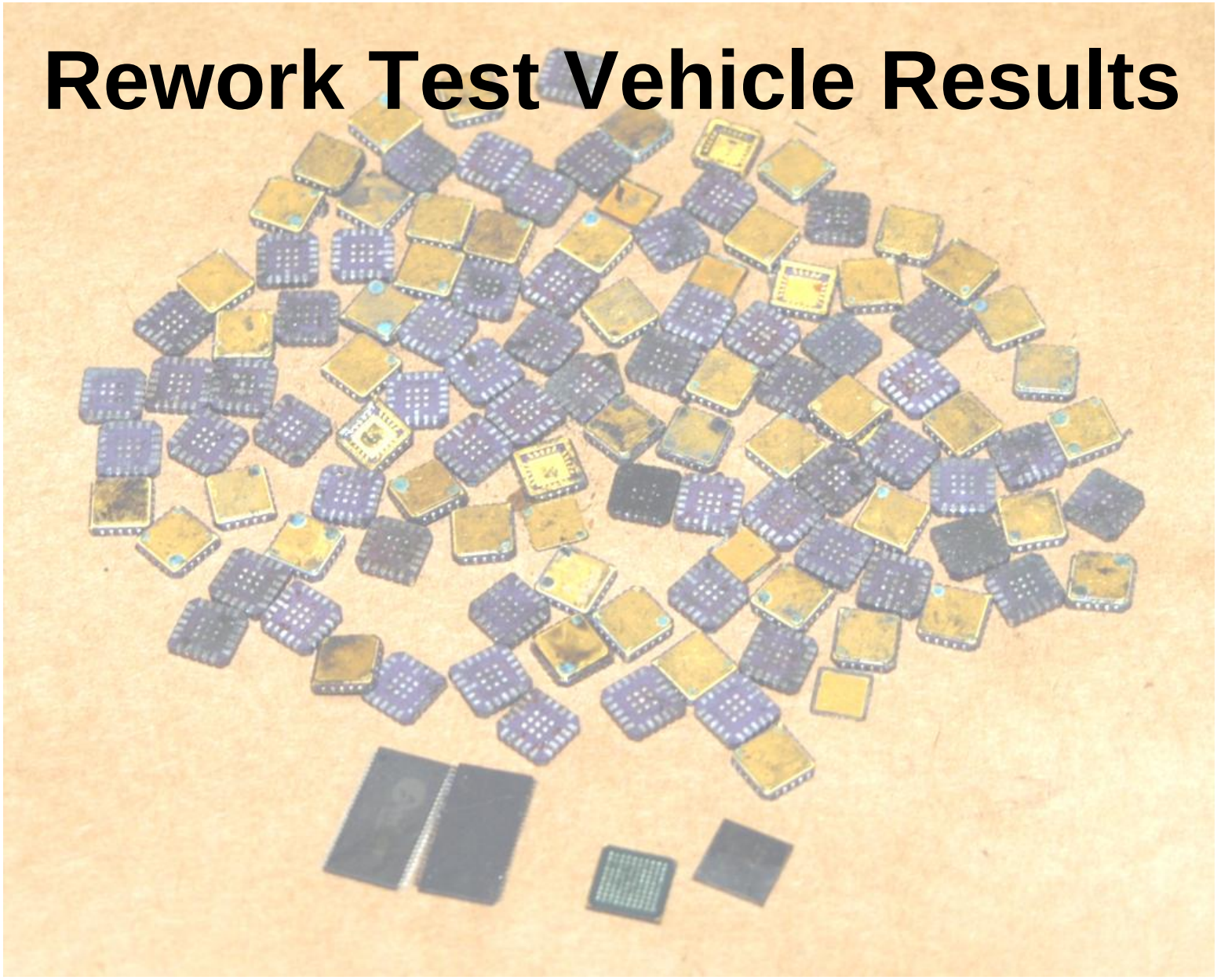


Mfg Lead-Free Solder Comparison

- TSOP-50 SnPb/SnBi vs. SnPb/SnPb
  - Data Point has Influenced Slope of Probability Line
  - Probability of Tin-Lead/Tin-Bismuth Lasting Longer Than Tin-Lead is 92% - Significant
  - Outlier

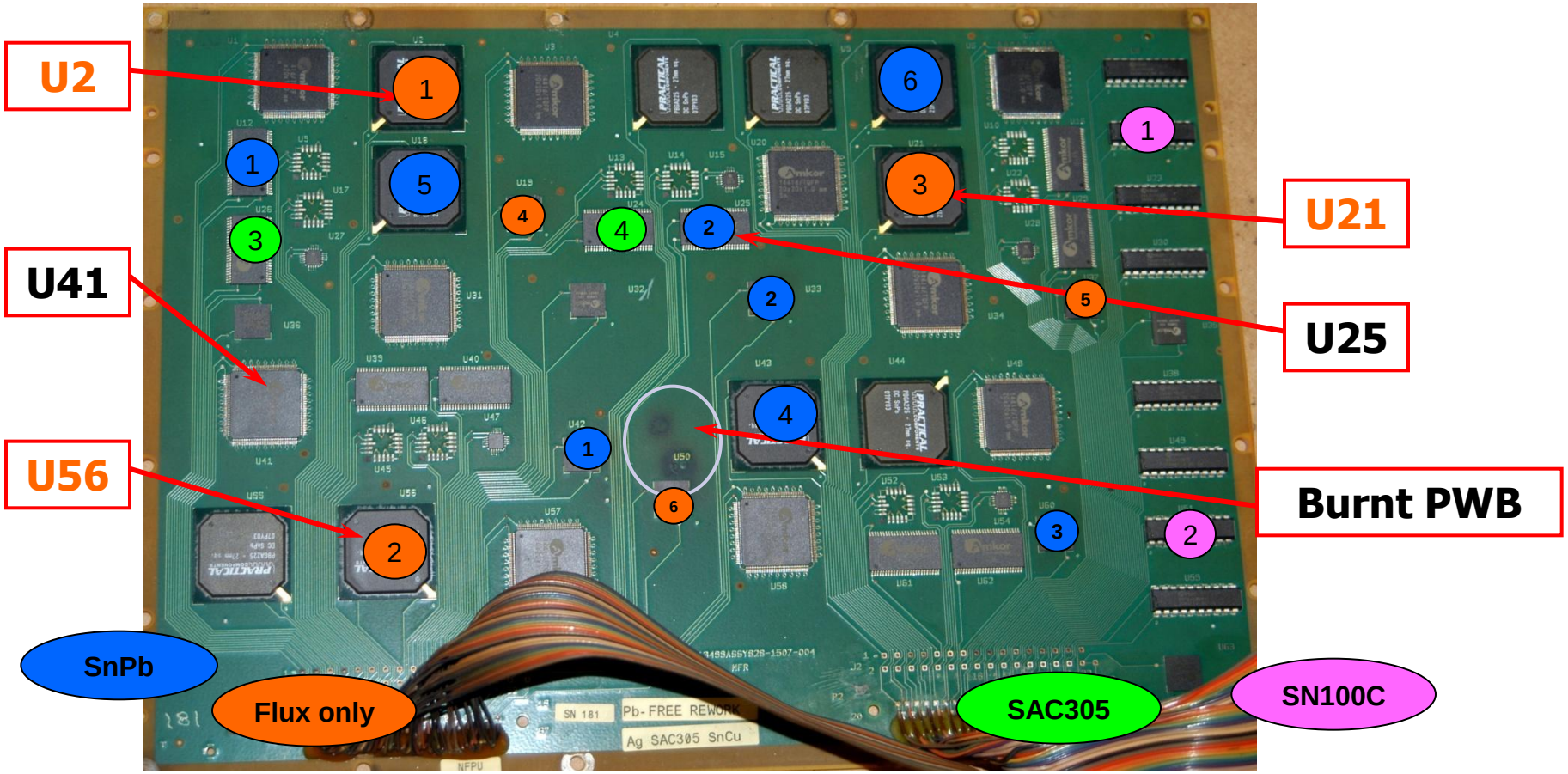


Rework Test Vehicle Results



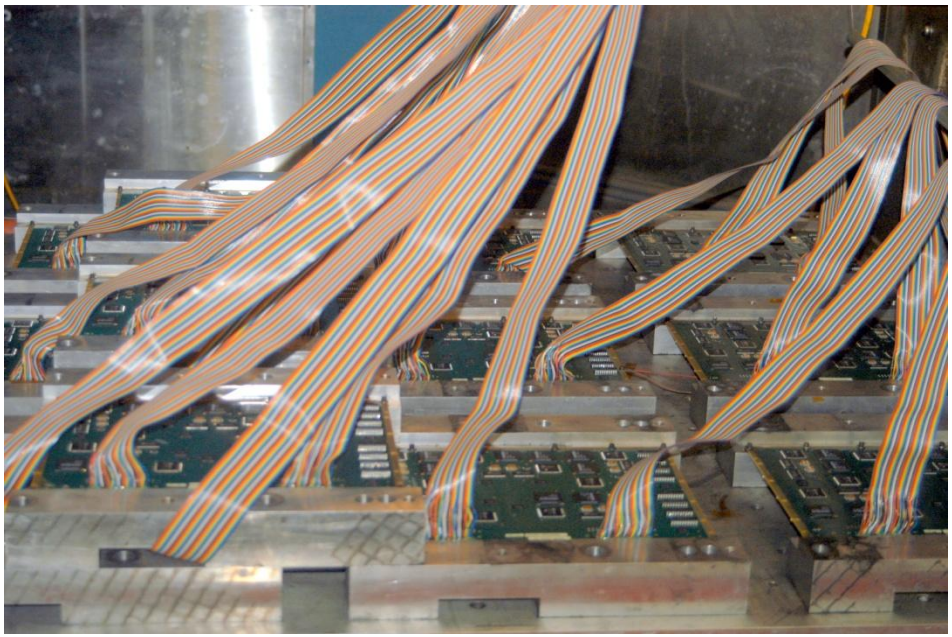
Result of Rwk TV SN 181 (Batch A)

- Multiple Early Life Failures, **Qty 3** BGA-225 Rwk with Flux Only/SAC405
  - U41 Not Reworked – Rework Induced Failure?



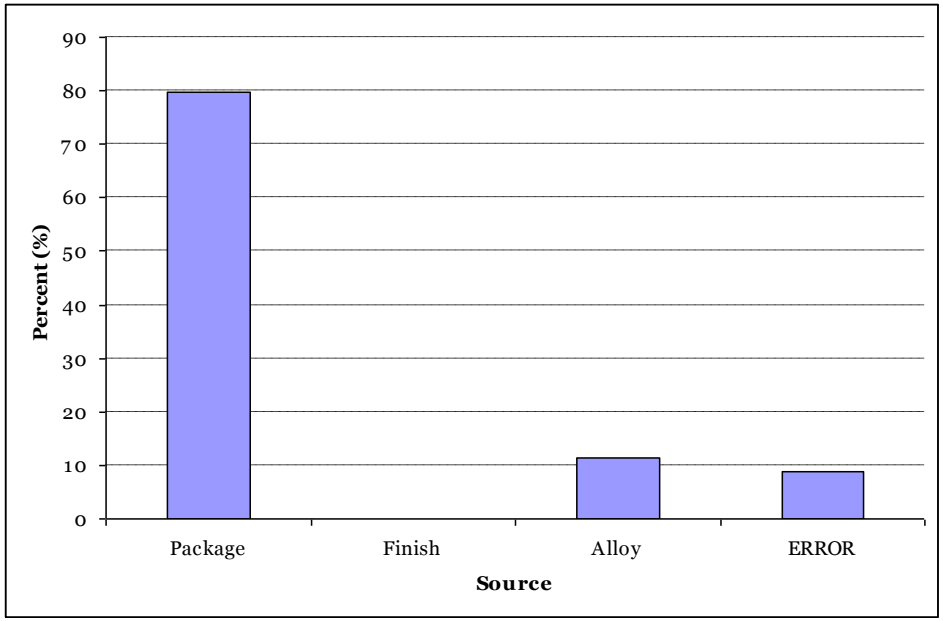
Summary of Rework Results

- High Number of Early Life Failures
- Did Not Reach 55% Component Failures after 650 Cycles
- Rework Impacted Adjacent Components
- Maintenance of Test Chamber Had an Effect On Results
  - Hammers being replaced
  - Less Severe Testing in Run 2 (Rwk)

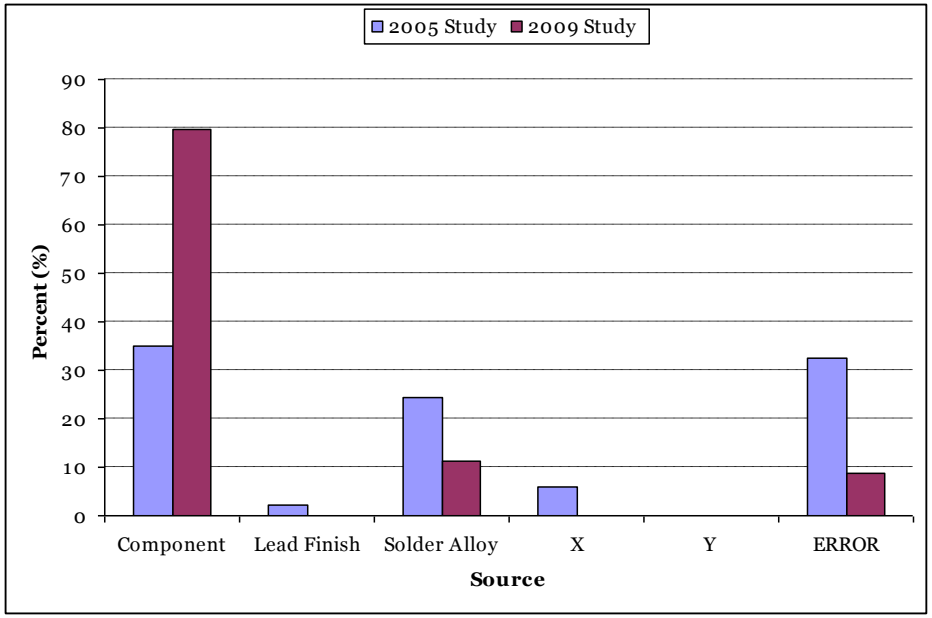


Statistical Analysis

- Charts of Variance Component Analysis

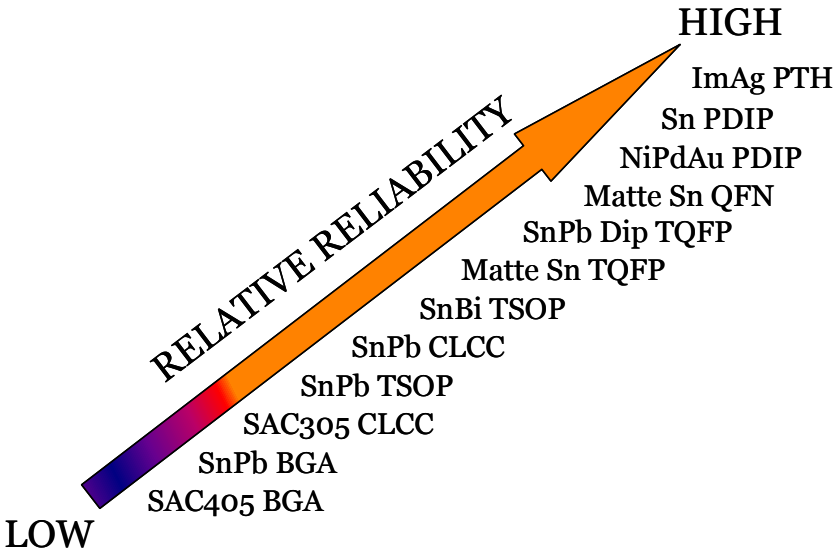


Manufacturing Data

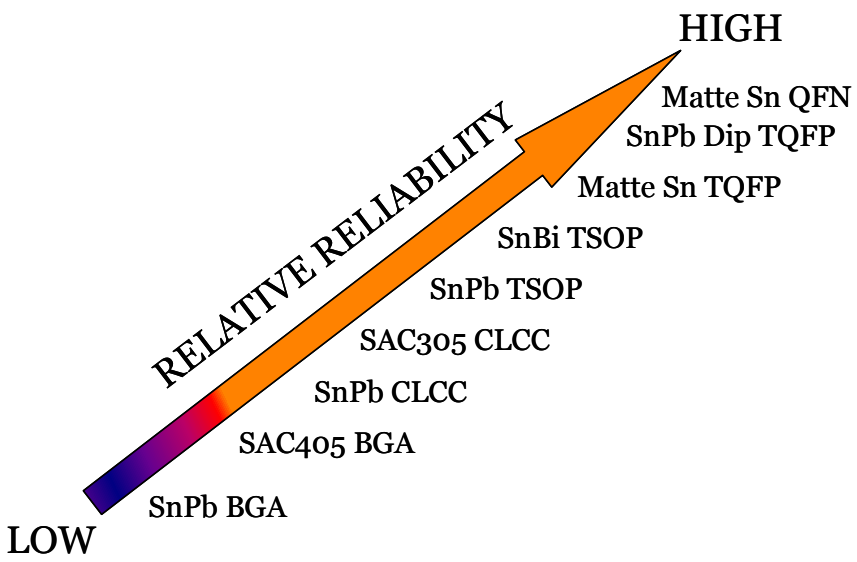


Comparison of 2005 JCAA/ JG-PP Project and 2009 NASA-DoD Project

Relative Reliability of Components



For Tin-Lead Solder and Tin-Copper on Mfg Less ENIG



For Tin-Silver-Copper 305 Solder on Mfg Less ENIG

Conclusions

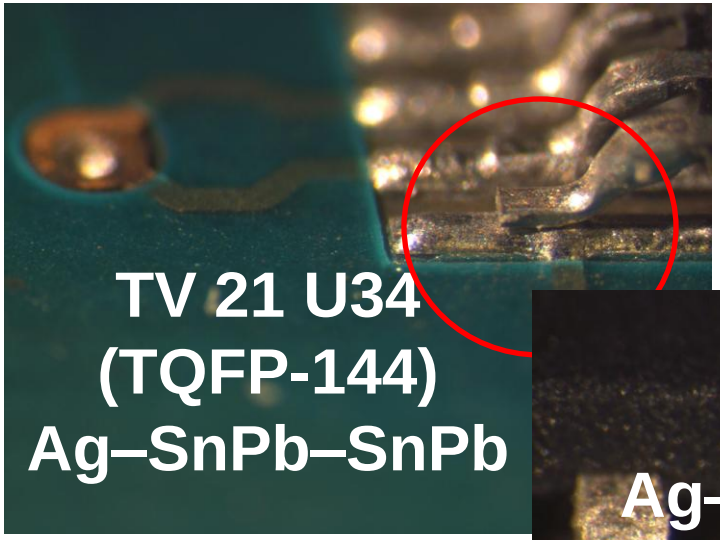
- Component Type Has Greatest Effect on Reliability Performance
  - Plated-through-Hole More Reliable Than Surface Mount Components
- Solder Alloy Had Secondary Effect
  - Tin-Lead Finished Components Soldered With Tin-Lead Solder Paste More Reliable
- CSP CTF Higher than Expected
  - Tin-Lead Components Soldered With Tin-Silver-Copper 305 Solder Paste Performed Best

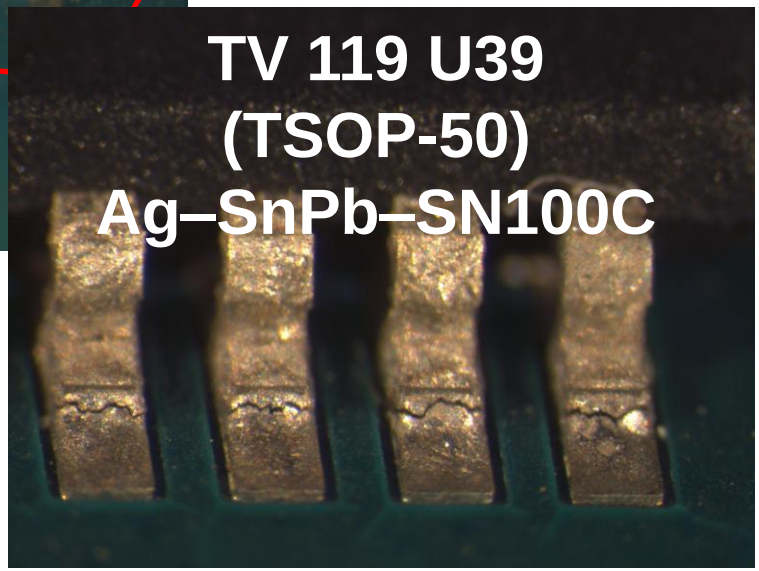
Conclusions

- Surface Finish – ENIG vs Immersion Ag
  - NOTE: Sample Size was Two Boards
  - One Exception, Performance of Tin-Lead CLCC-20 Components Soldered with Tin-Silver-Copper 305 Solder Paste on ENIG Surface
- Immersion Silver Surface Finish of Manufactured Test Vehicles Appear to Enhance Reliability of Solder Joints
- In General, Rework Components are Less Reliable

Conclusions

- Failure Analysis – In Progress
  - Provided by COM DEV®, Nihon Superior and Lockheed Martin Laboratories

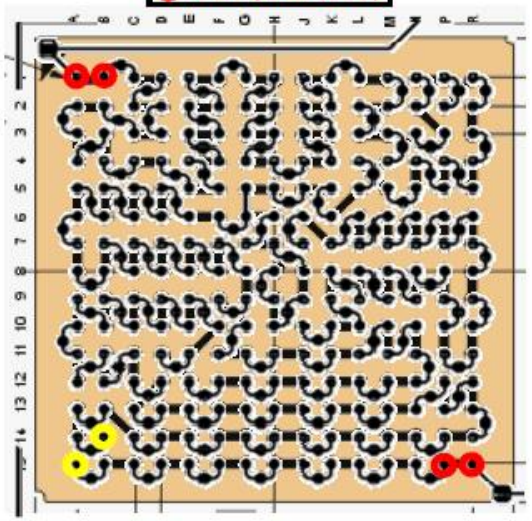


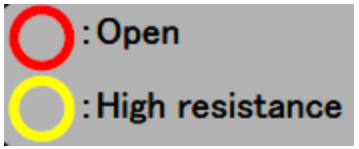


Test Vehicle 180

Pb-Free REWORK
Ag-SAC305-SnCu

⑤ U21(BGA225)





Questions